## SUMMARY OF PANEL DISCUSSION

Chairman: Alan Rosen
TRW

A. Rosen: Our topic is the spacecraft charging hazard to space systems and the credibility of that hazard to managers and systems designers who are charged with the task of doing something about it and also what constitutes a reasonable response to this perceived hazard. The panel members are a distinguished group and represent organizations that are concerned with the hazard. They may be regarded as technical spokesmen for their organizations and have the responsibility to do something about the perceived hazard. To many of us, they represent funding agencies, agencies that support much of our work. But, it is important to realize that they, themselves, are constrained to address what constitutes the "real" hazard rather than some imagined hazard.

The panel members are Major George Kuck, representing SAMSO; Robert Finke, from the NASA Lewis Research Center; Michael Massaro, from General Electric; William Lehn, from the Air Force Materials Laboratory; John Darrah, from the Air Force Weapons Laboratory; and Charles Pike, representing the Air Force Geophysics Laboratory.

Because of the late hour, our agenda and format for this discussion are aimed at giving each panel member an opportunity to respond to the key issues. I will open the discussion with some definitions and clarification of the topic problem. Each panel member will then respond, for about 5 minutes, to the problem. Then the session will be opened to general discussion.

If we could identify a well-defined threat to space systems, all tasks aimed at alleviating or eliminating that threat would be funded. Project managers and other people who are involved in the space program do respond to a threat that they perceive. The question is, can we put the spacecraft charging hazard in some sort of perspective on a scale of 0 to 10, where 0 is no hazard, 1 is a nuisance or outage of a second or less, 5 is an outage of a few hours, and 10 is some sort of catastrophe? At this time, we have failed to establish in a quantitative manner where the spacecraft charging hazard falls on this scale.

The elements that go into a quantitative definition of the hazard are the environment, the interaction of a spacecraft with the environment (the charging model and the arc discharge characterization or the frequency-amplitude domain) where the charge goes (a crucial element in determining the hazard to space systems), and the coupling analysis. What happens to the rest of a system during a discharge and what damage may occur seem to be unclear. Key members of the spacecraft design community cannot answer these questions. We have done quite a bit in describing the spacecraft charging environment and in defining a charging model. But we have failed in the area of discharges and coupling analysis and in doing the necessary work to define the hazard. Is it a valid hazard and what should be done about it?

G. Kuck: My introduction to the spacecraft charging problem was about 6 months ago when I was made project officer on the SCATHA program. Thus, I am the most junior member of this group. Although I was warned not to get involved with the SCATHA program and told it is a boondoggle, a WPA project for geophysicists, I do not hold this view. I believe it to be an important program and I think this is the perception of a large number of people. However, project personnel do not seem to consider spacecraft charging to be a hazard, and therefore nobody from the SAMSO Systems Program Offices attended this conference.

R. Finke: NASA has very little involvement with geosynchronous spacecraft. Although NASA is synonymous with spacecraft, we do not build and operate many geosynchronous spacecraft. We provide launch services. We did build the Applications Technology Satellite (ATS) spacecraft and were co-experimenters on the Communications Technology Satellite (CTS). And we are now taking part in the Tracking and Data Relay Satellite System (TDRSS) which is a big project involving a series of geosynchronous spacecraft.

So what is NASA doing in a spacecraft charging program? Well, we are technologists, and some of the early ATS data taken by Goddard indicated that there was a charging phenomenon. The particle detector on the ATS spacecraft indicated that in the geosynchronous environment spacecraft charged up. It is an interesting phenomenon. Others began reporting anomalies in their geosynchronous spacecraft, primarily the military communications spacecraft. Some of the commercial spacecraft people began talking about anomalies - switching of logic circuits, and so forth. We started looking at what might be the cause of this and suggested the charging-discharging phenomenon. It became apparent that there was a problem with spacecraft - a relatively serious problem. So as technologists we perceived that there was a technological need.

NASA had for years worked on high-voltage systems in vacuum, and some of us were familiar with the space sciences, instrumentation, and so forth. We felt that, with our background and experience, we could make a contribution. So, NASA decided to get involved in this activity. Eventually, we evolved the present intercenter spacecraft charging program and developed an interdependent cooperative effort with the Air Force.

We tried to use our ground-based facilities to simulate the space environment for testing. We demonstrated that, after a solar array was charged differentially, it arced and discharged. Kapton blankets, if not properly grounded, also exhibited arcing effects. We turned the electron beam in the vacuum system on to the Global Positioning Satellite (GPS) louvers and saw them arc, discharge, and flutter (the louvers opening and closing very rapidly).

From the ground test data, in this particular environment, it appeared that anomalies (arcing and sparking that would couple into the spacecraft system) could happen. So we began a modeling program and did more testing on the ATS-5 and ATS-6. We also developed an on-board monitor, a detector system, and put it on CTS. There were 215 transient events on CTS during a year in orbit. A transient event in this case is up to 60 spikes on the power bus. Fifteen percent of the solar-array power bus was lost after a particularly active flurry of transient events. So, again a problem seemed to exist that needed attention. We installed the same kind of monitor on the Orbital Test Satellite (OTS), and it is detecting transient events. The data have not yet been analyzed.

So, to address the question of credibility and hazards, we feel, from ground tests and analyses and our knowledge of the spacecraft charging environment, that there is a potential hazard but that it depends on the configuration and the spacecraft design. Transients can cause switching anomalies. We are trying to develop techniques to prevent these anomalies. As discussed in the papers given at this conference, NASA is publishing design guidelines and test data, but the acceptance of this technology by the user is highly dependent on our education of that user.

Think of this program as an R&QA function. If a user does not want to use qualified parts on his spacecraft but wants to risk using parts he can buy from Radio Shack, nobody can stop him except his sponsor or his boss. There is, perhaps, an unquantifiable risk - a risk that is going to vary a lot with the spacecraft, its design life, and its components. We may never be able to pin down exactly what the hazard is. But not looking at the charging criteria may be a lot like not using R&QA.

M. Massaro: I agree with most of Dr. Rosen's assessment. Whether a spacecraft charging hazard can be rated from 0 to 10 will depend on the spacecraft design. That is, you can probably have the full range of events, anywhere from 0 to 10, when an electrostatic discharge occurs, depending on the particular payload or spacecraft design.

Through internally funded research, government research contracts, and space hardware development contracts, GE has made some progress toward quantitatively assessing the effects of electrostatic discharges (ESD). At the systems level, we have analyzed ESD-produced structural currents and estimated their amplitude and wave shapes. We have measured the shielding effectiveness of our Faraday cage design to both radiated and conducted fields in order to determine the effects of electromagnetic-interference (EMI)-produced ESD on components and systems. Again, at the systems level, we have performed ESD radiated-spray testing on telemetry and command systems and on communications payloads while monitoring system performance. At the component level, we have performed current-injection tests of blanket bonding and grounding techniques to determine degradation of electrical grounds. We have performed electron bombardment tests of materials to determine optical and thermal degradation and discharge characteristics. We have measured spectrum signatures of materials that produced ESD. That is, we have measured the magnitude of the radiated-field spectrum produced by ESD in electron bombardment tests. Future approaches to quantitatively assessing the effects of ESD are as follows: large-scale environmental testing of systems while monitoring system performance parameters, as discussed by members of the European space community; development of combined-effects facilities to more accurately simulate the space environment for monitoring of materials responses and parameters.

In response to the question whether the hazards of spacecraft charging have been overestimated, the scientific community's reaction to most new phenomena that pose a threat to system performance tends to be very conservative. This results in excessive design and test requirements in an effort to control the problem. As the spacecraft charging phenomenon becomes better understood, more realistic design and test requirements will emerge. But the threat posed by spacecraft charging and discharging is real and dangerous, as pointed out in the last two conference papers. For example, it can lead to thermal degradation of materials, communications performance degradation, logic upsets, sensor degradation, and even spacecraft failure.

However, we may be erring in attributing most spacecraft anomalies to charging. Some of the occurrences may be attributable to poor design. Currently, there is no system to identify the exact source of anomalies. We also do not know enough about the effects of ESD. That is, exactly what happens when there is a breakdown, what are the coupling mechanisms, what are the systems interactions, how does ESD couple into spacecraft systems? In short, there is a credibility gap in perceiving the actual hazard.

Government agencies should continue to fund basic research into modeling and testing efforts that will help our understanding of the charging-discharging phenomenon; sponsor large-scale system-level test efforts; develop and recommend definitive, unambiguous, cost-effective design procedures that can control the effects of ESD; make design guidelines a contractual requirement but allow the design procedures to be tailored to the specific mission and payload; sponsor development of a standard, practical, ESD monitoring system that can become available as government-furnished equipment to spacecraft manufacturers and provide its interface requirements. Private industry should use good guidelines that are presently in practice, for example, EMI shielding of critical signal lines; use engineering spacecraft charging models; apply systems-level analysis to validate designs; apply recognized, standardized test procedures to ensure good design.

W. Lehn: As evidenced by this conference and the previous one, the spacecraft charging-discharging phenomenon exists. It is now recognized as a phenomenon that is encountered by satellites and other space systems, particularly those that operate in the geosynchronous environment. Recognition of the phenomenon and proper consideration of it in spacecraft design can reduce its potential effect from a hazard to a cause of disruptions or anomalies or can eliminate it completely, as evidenced by the experience with GEOS. GEOS was designed to be 96 percent conductive and has reported no instances of any disruptions or anomalies that could be attributed to spacecraft charging. On the other hand, Meteosat-1 is reported to be performing extremely well in spite of occasional (about 1 per week) status changes. These changes are attributed to surface discharges (spacecraft charging) resulting from the presently rather high solar activity. A recent anomaly in the on-board satellite clock system of an operational satellite has been attributed to spacecraft charging, but the event has not been duplicated in the laboratory. Spacecraft charging is often offered as the cause of certain satellite anomalies without ~~any real~~ direct supporting evidence. There is only one reported case in which spacecraft charg- was established as the cause of the catastrophic failure of a satellite - a DSCS power system.

It is my opinion that spacecraft charging is not really a hazard but a problem that must be treated early in the design of a satellite. By incorporating the proper standards and guidelines it can be designed out of a satellite. As reported earlier, an electrostatic discharge (ESD) control program has been incorporated into the design, development, and testing of the DSCS III satellite and promises to minimize or eliminate the effects of spacecraft charging ESD. The preliminary spacecraft charging standard and the design guidelines for the control of spacecraft charging reported in be previous session are two of the key activities in the cooperative NASA-AF spacecraft charging investigation. When updated to include SCATHA spaceflight data and formalized, these documents will provide the basis for the design of charging-free operational satellites. Certain scientific satellites whose mission includes measurements of very low-energy radiation and charge buildup present special problems that must be handled on an individual satellite-by-satellite basis.

The many papers presented at this conference are ample evidence of the progress that has been made in qualitatively and quantitatively assessing the overall phenomenon and its potential for causing problems with various spacecraft systems and subsystems. SCATHA will add greater insight into the overall problem and provide the data needed to further define the dynamic, often very rapidly changing, geosynchronous radiation environment. The SCI and ML12 experiments will provide valuable materials performance and response data and relate spacecraft charging with contamination. A thorough understanding of spacecraft charging and related modeling activities is expected to take many years, but the standards and design guidelines to build satellites essentially free from any major hazards or anomalies should be available within the next 2 to 3 years.

Is the Air Force response to spacecraft charging reasonable? Spacecraft charging is only one factor that must be considered in the development and application of new satellite thermal-control coatings and materials. Table 1 shows these factors.

TABLE 1. - PROTECTIVE THERMAL-CONTROL COATINGS AND MATERIALS

FOR EXTENDED-LIFE SURVIVABLE SATELLITES

- Tailored optical properties
  $\alpha_s, \varepsilon$

YOUR FAVORITE SATELLITE

- Space stable 7-10 years ($UV$, $e^-s$, $P+$)
- Low contamination
- Reduced space charging
- Hardened for nuclear and laser effects
- Low-intrinsic-signature materials (visible, IR, radar)
- Shroud and decoy materials

First and foremost, the new materials must have the required thermo-optical properties to function as thermal-control coatings. These materials must be stable to the natural space environment for the life of the particular mission and, depending on the specific mission (communications, surveillance, etc.), be very low-contamination sources and/or be able to control spacecraft charging. In addition to natural-environment survivability, design of Air Force operational satellites must also consider the vulnerability factors in the right-hand column of table 1. Certain of these factors were in the realm of science fiction not too many years ago. A space-stable, low-contamination, reduced-space-charging material that is suited for a commercial satellite might be totally unsatisfactory for an Air Force satellite because of deficiencies in hardness properties.

In summary, spacecraft charging is only one factor that must be considered in the design, development, and testing of spacecraft. Proper application of the spacecraft charging standard and the design guidelines for the control of spacecraft charging from the Air Force - NASA cooperative effort should reduce or essentially eliminate spacecraft charging as a major concern in future satellites. Very large space structures represent a special case, and further effort and analysis will be required. There is a definite lack of secondary emission, radiation-induced surface and bulk conductivity, photoconductivity, and other classical materials data needed to support the spacecraft-charging modeling activities and to form the basis for developing new and improved thermal-control coating materials. Responsibility for developing such data within the AF-NASA spacecraft-charging working group has not been determined.

J. Darrah: At the Air Force Weapons Laboratory, we are principally concerned with nuclear warfare and the survivability of spacecraft. There is thus less ability, through normal experience in peacetime, to check potential spacecraft performance. The performance of spacecraft in ambient and enhanced electron environments (e.g., solar substorms) by no means explains what would happen in a nuclear explosion. Here we have not only the electron environment, but also the effects of gamma rays (which cause a number of charges to move in a spacecraft, potentials to develop, currents to flow, and the conductivity of materials to change), as well as X-rays and photoelectric phenomena (one principal mechanism called the system-generated electromagnetic pulse (SGEMP) effect). And in some cases there may be synergistic effects, depending on the state of the charge, between the electrons and the gamma rays or X-rays. The current in the spacecraft can be significantly higher, particularly in the high-energy portion, during a nuclear explosion than during a solar substorm. Consequently, problems that might not be experienced during spacecraft operation in the natural space environment may become problems in the nuclear environment. Essentially, the time to accumulate enough charge to cause discharges and difficulties could be very long in the natural environment but could be a few orders of magnitude shorter in the nuclear environment. So this is a different problem and cannot be evaluated well from peacetime experience.

Nuclear tests above the atmosphere have started with the Starfish test, which is the first of the Fishbowl series of high-latitude tests. There are not a lot of data from these tests. However, there has been some review of the data, and some spacecraft anomalies do not seem to be attributable simply to total dose effects, for example, solar-cell degradation and prompt TREE effects, which clearly lead to eventual spacecraft failure. So some nuclear anomalies may be related to spacecraft charging. The problems are clearly not catastrophic (e.g., burnout of most of the major electronics) or there would be a lot of panic.

The best data available clearly come from space tests rather than from laboratory tests. Unfortunately, there seems to be a lack of cooperation between the spacecraft designers and operators and the spacecraft-charging community. So there is no clearinghouse where incidents of anomalies are reported and the seriousness of the problem is investigated systematically.

Progress will never be made on the total engineering problem down to the interface level without laboratory experiments on the full systems level. Basic modeling phenomenology physics by itself will not do very much. The solution to this problem is not going to come from first-principle physics and it is not going to come from small-sample and limited-geometry tests. First-principle calculations for the nuclear case, including synergisms, produce results that are not real. If they were real, total burnout of spacecraft electronics would have occurred in many cases. The problem of how dangerous spacecraft charging is will be resolved by large-scale laboratory experiments backed up by a reasonably prudent amount of even larger scale laboratory experiments and theory.

Although spacecraft charging is obviously a hazard to some as yet undetermined degree, some operational problems mentioned by the panel members are simply a matter of design. So anomalies cannot be used as proof of how important a problem charging is.

No one, neither systems house nor government agency, is capable of determining the effect of a nuclear explosion on spacecraft charging. This effect could become of prime importance during wartime and is a present concern of the systems houses. Even the effect of a peacetime explosion causes concern.

In conclusion, the Air Force Weapons Laboratory is going to try, within the limits of our understanding, to reproduce the spacecraft charging phenomenon in the laboratory. We will also try to conduct systems-level experiments with reasonable phenomenology across the whole spectrum of electron energies.

C. Pike: The reliability and survivability of military mission spacecraft is of paramount consideration. In this program, technology dollars must compete with systems dollars, which are certainly far more significant. A technology base must be developed and transferred to the users. Fortunately, the hazard of spacecraft charging was recognized many years ago by Air Force Headquarters. The Air Force then established an interdependent technology program with NASA. As this program has progressed, the list of operating anomalies from military and civilian spacecraft has grown and provides a very strong justification for pursuing our program. Indeed, there is a problem, although what is perceived by one program manager as an anomaly of great concern to his program would be merely a nuisance to another program manager. This is a subjective area where candor is often lacking. It is very difficult to assess what, from an operations and reliability viewpoint, is a hazard.

Some significant results of the Air Force - NASA program were presented at this conference. Very significant also is the presence at the conference of the aerospace industry, especially the large corporations who are the contractors for the mission programs. They will implement the technology we develop and are strong spokesmen for this technology.

MIL standard 1541, which is a charging-related test standard, has had a significant impact on satellite development. The only satellite development program using this standard is DSCS III. This satellite is being developed in the context of the AF-NASA technology program. The growing list of anomalies have occurred on satellites that were designed many years ago and have had band-aid fixes to them. The technology that we have been developing in the past 2 to 3 years is being incorporated in the DSCS III program. Dr. Massaro's paper on charging calculations on DSCS III shows that indeed the satellites will see high voltages and that in some cases steps have been taken to mitigate that voltage buildup. Gil Condon's paper shows the design and test program that General Electric is pursuing.

The DSCS III program is developing our next generation of communications satellites, a significant payoff from the AF-NASA technology program. The spacecraft charging hazard has been recognized, a technology base has been developed, and it is being implemented. The Air Force Geophysics Laboratory has been successful in defining the spacecraft charging environment and we know where the technology gaps are - in the field-alined fluxes and ionic composition. SCATHA will certainly provide needed information. In conclusion, there has been strong progress in the technology program. Technology transfer has been proceeding very smoothly. These conferences are a very important part of the transfer process. Technological development generally requires at least 10 years, and we have only been involved in it for 2 or 3 years. Only in 1972 to 1974 did spacecraft charging come to the forefront. In a very short time a lot of progress has been made, and the technology is being applied in our next generation of communications satellites.

<u>A. Rosen</u>: There is one person that hasn't been represented - the person who is responsible for assuring that a system that is about to be launched survives. That person generally needs a measured response to many, many hazardous situations. He really doesn't know whether to immerse the spacecraft in a gigantic swarm tunnel and subject it to electrons and ions or merely to do an air test with simulated arcs. He does not even know what sort of arcs to use. Subjecting the spacecraft to unknown arcs that may not be representative of the in-orbit condition could be a greater hazard than not testing it at all. Should he do a coupling analysis program, which could be very expensive? Or a charging analysis? If he grounds some of the thermal blankets, does he need a verification program to ensure that everything is grounded? These questions haven't really been addressed. He would like to have a measured response to what he considers to be the hazard, but he doesn't know what a good measured response is. This is why some quantitative assessment of the spacecraft charging hazard must be made.

Are there any questions of the panelists among each other? Then, the discussion is open to the audience.

J. Nappli: I am with RCA American Communications. At the conference 2 years ago there was a similar panel discussion, but the theme was a little different. The panel members planned to tell industry - all users, systems designers, and manufacturers - that they wanted to plot orbitial arcing to see what the environment is like. They were going to supply sensors to industry. Unfortunately, no action was taken. I think for that very reason there is a credibility gap.

Three of the five commercial users of satellites attended the last conference. At this conference, I am the only commercial representative. The five commercial users have 18 satellites in geosynchronous orbits. If there wasn't a credibility gap, these users would be represented here. In the next couple of years, there will be two more commercial users. They are not represented at this conference either. Unless it can be demonstrated that electrostatic discharging (ESD) will either curtail an 8-year mission and thus cause a loss of potential profit and earnings on a commercial satellite, there is going to be a credibility gap with the commercial users. That is one of the problems.

As far as incorporating sensors on the spacecraft, I tried to bring the message to my management but was met with the credibility gap. They said sensors would be nice to have if the procurement and installation were free. The procurement from NASA was free. The installation by the contractor was not. My management wanted to know what government agencies that have launched satellites in the last 2 years have these sensors on their own satellites. That is a hard question to answer and is one that I would like to put to the panel.

Mike Massaro from GE would like to see many test programs conducted. If all these test programs are sponsored by the government, fine. Would GE run an internally funded program to test spacecraft in plasma tanks to show that there is a hazard or that there is a solution to the hazard? I think that, if GE wasn't funded by the Air Force and NASA, that the position wouldn't be taken. I feel that I'm being a realist here and I have one more question. Is DSCS III going to have any sensors on board?

R. Finke: All government-sponsored spacecraft put into geosynchronous orbit have had sensors. The Canadian government put a sensor on CTS. ESA put a sensor on OTS. Both were simple sensors that counted transient events. But both these government-sponsored spacecraft have them. Again, NASA has not sponsored or built spacecraft, with the exception of TDRSS. Ms. Bever represents the Goddard Space Flight Center and TDRSS. The Director of Goddard, Dr. Cooper, has requested the support of the Lewis Research Center in investigating charging problems and design criteria for TDRSS. We are supporting that project. NASA, again, just is not in the geosynchronous spacecraft business. But we do take spacecraft charging seriously.

G. Kuck: Something like a Transient Pulse Monitor (TPM) was installed on an operational Air Force satellite many years ago. But the present spacecraft charging program is more expensive than just a single instrument. The P78-2 satellite alone costs over $45 million. The SCATHA portion is just over $5 million. So the Air Force has invested over $50 million in trying to identify and solve the spacecraft charging problem. I have seen evidence at this conference that GE is working on the problem. So, the existence of the problem is recognized. Now, if we do our job right, the problem will no longer exist in 2 years for the types of spacecraft being built now or to 1980 or 1985. Except for kilometer-size structures, the problem will be solved.

M. Massaro: In response to the question about ESD monitors, SAMSO in their original contract did not request a monitor system on DSCS. Actually, General Electric proposed it in our response to the proposal. However, later, because of budgetary constraints and mainly because we don't think ESD will be a problem on DSCS because of the materials being used and the special precautions being taken, GE decided not to install an ESD monitor. However, the Japanese (our customer) during their contract with us requested that we "ESD proof" their Broadcast Satellite Experimental System. They, as a user, were concerned about it.

In response to the question about spacecraft outage, the domestic common-carrier satellite companies who lease transponders on the Domsats are terribly concerned about outages due to solar activity or any other cause. We may not be too aware of what the outages are, as pointed out by another panel member. A lot of spacecraft manufacturers and operators do not want to discuss the problems they have had with their systems. Some representatives from Comsat Laboratories are present and they may want to discuss the outages on the Intelsats because they do seem concerned about the problem.

S. Bosma: Mr. Darrah said that a small-scale test would not be relevant for engineering problems on a spacecraft. However, if you take any material, you start with what its basic behavior will be. You establish its outgassing properties, its thermo-optical properties, etc., with small-scale laboratory tests. You also want to determine its electrical properties. It would be quite normal to apply a screening test method on the electrostatic properties of materials. In a sense this is already taking place. Furthermore, Mr. Darrah said that there are no solutions for electrostatic problems. I think that Dr. Lehn will agree that most of the thermal-control coatings have conductive alternatives. There are conductive black paints, conductive optical solar reflectors (OSR's), and metal surfaces that are themselves conductive. Only the problem of a conductive flexible solar reflector has yet to be solved. In 2 or 3 years solving the electrostatic problem will be standard practice.

J. Darrah: Although the materials tests mentioned by Mr. Bosma are of use, they have limitations that severely affect the original question of the credibility of spacecraft charging as a hazard. From a small area of material it is difficult to establish, even from a basic physics standpoint, the area of thermal blanket or the area of solar cells that contributes to an arc. That is, as material is added to the spacecraft, on the outside and the inside, how large an area contributes to a discharge current at what time? Small-scale experiments do not even establish the boundaries of the problem. So you don't know how much increasing the area to more of a systems level might contribute to an arc. So there is not a bound on current, localization, or time history from small-scale experiments. That is why larger-scale experiments are required. The whole spectrum hasn't been treated, particularly the nuclear case. It isn't clear that results from thermal blankets and external coating tests can be used to evaluate the potential of discharges in printed-circuit boards, in cables, and in other dielectrics in the interior of the spacecraft during nuclear warfare. The coupling problem of arcs in many of these latter cases is a much more complicated problem than the insight into the physics that comes from the small-scale samples. The small-scale experiment results on coupling depend very much on the design.

W. Lehn: A lot of progress has been made in the materials charging aspect, in trying to modify FEP Teflon or Kapton to be conductive. But that is only part of the problem. The right side of the table I presented earlier shows the more severe problem, which hasn't been broached at this meeting. Peacetime use, as indicated, is not a problem. In another situation, some of the best materials for solving the charging problem have been totally inadequate for those problems listed on the right. We have some solutions, but we don't have the solution that will fill all the Air Force requirements. We have some materials, data, and approaches but also many questions. The question of in-depth charging is still open. The need for bulk conductivity of materials has not been determined. There is no good, adequate approach to provide a substitute material for any current material that has all the optical properties, long lifetime, and high bulk conductivity and that can be substituted directly.

G. Kuck: The question of the level to which you test is one with which you are always faced. No matter what type of environment is involved, you must decide whether you want to simulate the environment or the effects of the environment. You have to differentiate between verifying that the system will be able to operate in that environment and making a system that operates reliably in the effects of that environment. All satellites that are hardened for SGEMP and for some of the nuclear effects are not tested in underground nuclear tests. We try to test the systems some other way. We specify to the contractor what type of test the Air Force or the customer requires so that the operational spacecraft will be proved reliable, without costing a percentage of the gross national product. One of the approaches taken in the SCATHA program is to try to fill that gap between the environment and the effects of the environment. The P78-2 satellite will check what the EMI and RFI environments are in space. A laboratory scale model will be tested, possibly including a spray test, to see what its EMI-RFI environment is. The laboratory environment can then be related to what we see in space. We will then try to relate the laboratory environment to the results of small-sample tests in order to complete this logic loop. Relatively inexpensive tests that model all those effects will be levied on the contractor. It is a money and resources problem.

Earlier I was remiss in not saying what I think the government's responsibility is. The government's responsibility is to make sure that we get the tests and procedures that the contractor can adapt to the system he is building. In final analysis, we need a combination of analysis, testing, and whatever so that we can assure the satellite sponsor that the satellite will operate reliably when we launch it. If there is an anomaly, it will not be anywhere on the scale between 1 and 10, but will be about 0.5. To gain an extra 0.1 percent in reliability would cost too much. The question is how to tie together the small-scale test, the larger scale test, and the actual operation in the space environment. Then, how does one model the effects and define the appropriate, affordable, systems-level test that gives you confidence before a launch. You have to look at the whole system.

Member of audience: Would the panel comment on the launch time of SCATHA relative to the 11-year solar sunspot cycle?

C. Pike: In the past 6 or 9 months, solar activity has gone up very dramatically and, more recently, it appears to be plateauing. SCATHA will be orbiting and collecting data near the sunspot maximum, a very disturbed time.

E. Whipple: When Dr. Rosen formulated his point on a credibility gap, he put it in terms of questions to modelers: Have they really done their job? Have the environmental modelers really done things properly? Have the sheath modelers done their job? Have the discharge modelers really modeled that properly? That seems to be putting the burden on the theoretical side. I'm enough of a theoretician to know you never trust a theoretical answer but you should look to the data. I'm disappointed, in a way, that the people who have flown spacecraft, that is, the spacecraft designers and builders, have not found the causes for these anomalies. Why aren't they more interested? Is there a conflict of interest, perhaps, in that the designer doesn't want to admit that his design didn't take care of this particular problem? Why hasn't there been more work? We need to know more about the anomalies that have already occurred.

A. Rosen: I didn't put the whole burden on the theoretician for solving or not solving the important problems. I did put some of the burden on them; but also some on the experimentalists for not tackling the right problems; and also some on the project managers, who are responsible for disseminating funds, for not seeing to it that the right problems were tackled. And, I'll accept the responsibility myself for being blind 2 years ago to what the real problems were. So the theoreticians are not being blamed for everything. The anomalies are an exercise in frustration for most project managers. It is almost impossible to reconstruct events as they occur on a spacecraft. Large sums of money - about $10 million in half a dozen cases - and quite a bit of effort have gone into this. The results have been inconclusive in the cases I have been involved with. So, we are really chasing our tails. On the one hand the spacecraft designer refuses to put diagnostics (transient monitors) on the spacecraft because monitors are not going to fix anything for him. On the other hand, when he does get into trouble, he is in a dilemma and can't determine what the source of the problem is.

E. Whipple: Why hasn't there been a strong emphasis on diagnostics? A small TPM monitor is not expensive.

A. Rosen: The people who are responsible for operational spacecraft generally don't want to undertake a research and development program by using diagnostics monitors.

G. Kuck: Elden, it's money.

J. Napoli: One of the real reasons is that the level of problems has been about 0.5 on a scale of 0 to 10 - problems that have not caused any outages, at least none that we can attribute to spacecraft charging. In my 3 years of satellite operational experience - that 3 years is a total of 6 if you take the two satellites - we have not had any problems or any outages that we can attribute to spacecraft charging. That is true, in general, with all the commercial satellite programs. Without an outage caused by some unknown, you can't justify the cost of sensors.

S. Deforest: That statement doesn't make sense unless we add the qualification that all anomalies have been tracked down to a source without these diagnostics being made.

J. Napoli: The anomalies we haven't been able to track down are so insignificant that they are not of any major concern.

A. Rosen: There was one anomaly that was a 10 on a scale of 0 to 10 and it was tracked down very vigorously. This total failure and loss of a space system was attributed to a charging phenomenon. There was no other cause for that failure that was as credible as a charging and discharging event. Although we cannot say that it definitely was the cause.

M. Massaro: Maybe the design features of the RCA satellites precluded any problems with ESD. In other words, ESD did not affect the components because of the design procedures RCA had used for these two spacecraft. In other words, it is fortunate that you didn't have any problems.

J. Napoli: Let me give you a little background on that. About 3½ or 4 years ago myself, as a user, and our contractor, RCA Astroelectronics of Princeton, toured the country after we had read the report about that particular catastrophic problem that Dr. Rosen made reference to. We were in the design phase at that time so we were concerned. That is the very reason why I'm here and have followed this subject for the last 4 years. We tried to find out what the problems were and what to do to avoid them. Then we went through all the ramifications and reviewed all the test data we had picked up by contacting people in the optical coating industry, in the other contracting industries, at SAMSO, and in various other places. We looked at our basic design, but even so we made no changes other than those we had originally planned to make anyway.

A. Rosen: At this point I would like to close the session.